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GROWTH CHARACTERISTICS OF THE SPOTTAIL PINFISH, *Diplodus holbrooki*, OFF NORTH CAROLINA

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Abstract: Whole sagittal otoliths of 349 spottail pinfish, *Diplodus holbrooki*, ranging from 55 to 365 millimeters total length (TL), were examined to determine ages of individual fish and growth. Sectioned otoliths were also analyzed, but were less useful than whole otoliths for determining ages. Samples were obtained from North Carolina recreational headboat landings from 1993 through 1995. The species is becoming increasingly important to the North Carolina headboat fishery. Most of the fish sampled were caught off Beaufort, NC. The oldest fish was 11 yrs old and measured 365 mm TL. Rings formed on most otoliths during spring (March–May), and are thus considered to be true annuli. Mean back-calculated total lengths (in mm) at ages 1–11 were 120, 168, 198, 221, 237, 253, 270, 288, 296, 298, and 310, respectively. The von Bertalanffy growth equation for the species using back-calculated data from the last annulus was $L_t = 332\ (1 - e^{-0.19(t+1.50)})$, where t = age in years. The equation for all back-calculated data was $L_t = 308\ (1 - e^{-0.26(t+0.98)})$. The length-weight relationship for spottail pinfish was $W = 4.5 \times 10^{-5}\ TL^{2.82}$, where W = weight in grams. Conversion of total length to fork length may be obtained by the equation: FL = −2.75 + 0.88 (TL), and fork length to total length: TL = 4.52 + 1.13 (FL). Estimates of total instantaneous mortality (Z) range from 0.77 to 0.89 depending on year and geographic area. Age at full recruitment to the fishery was age 6 determined by catch curves. A fish age–fish length key was developed.

Key Words: spottail pinfish; age and growth; North Carolina.

INTRODUCTION

The spottail pinfish, *Diplodus holbrooki*, also known as Holbrook's porgy (Breder, 1929), and sailor's choice (Hildebrand and Schroeder, 1928), is a medium-sized sparid fish of little commercial importance. Specimens up to 356 mm total length (TL) have been reported (Hildebrand and Schroeder, 1928; Walls, 1975), but individuals greater than 325 mm are rare. The species is distributed from Chesapeake Bay southward along the Atlantic coast to the Florida Keys, and then northward along western Florida to include portions of the northern Gulf of Mexico (Caldwell, 1955; Manooch, 1984).

Spottail pinfish typically inhabit two types of habitats in the South Atlantic Bight (i.e., North Carolina to Cape Canaveral, Florida). Juveniles are found in high-salinity coastal waters on sparsely vegetated sand-mud substrates, as well as around pilings and jetties in bays and harbors. Adults populate ocean waters over irregular substrates such as rock piles, reefs, and wrecks to a depth of about 33 m (Manooch, 1984). The species was reported as frequently seen along breakwaters and piers on the coast of North Carolina by Hildebrand and Schroeder (1928). More recently, Clavijo et al. (1989), Linquist et al. (1989), and Pike and Linquist (1994) have conducted research on *D. holbrooki* inhabiting artificial and natural reefs off the North Carolina coast. They conclude that the spottail pinfish is one of the more abundant reef-associated species.

Although not highly valued by commercial reef fish fishermen, spottail pinfish have grown in importance to the recreational headboat fishery, particularly in North Carolina. A shift in landings of *D. holbrooki* is definitely occurring and has resulted in elevating the species to the status of an important component of the inshore, recreational snapper-grouper fishery operating from North Carolina ports. The reason for the increased landings is not known. From 1981–1989 annual headboat landings in North Carolina averaged 8,173 spottail pinfish (pers. comm., R. L. Dixon, Beaufort, NC). The annual average increased to approximately 25,000 fish by 1990-1994. Overall, North Carolina landings of spottail pinfish have averaged 23–85% of the coastwide total for the species from Beaufort, NC, through Key West, FL. The percentages for 1990–1994 were 82, 85, 73, 71, and 78, respectively.

Most research on spottail pinfish has concentrated on ecology and feeding (Reid, 1954; Caldwell, 1955; Livingston, 1982; Stoner and Livingston, 1984; Linquist et al., 1985; Hay and Sutherland, 1988; Clavijo et al., 1989; Linquist et al., 1989; and Pike and Linquist, 1994). The species has been described as an important temperate herbivore (Hay and Sutherland, 1988), although a variety of plant and animal material has been found in the diet (Linquist et al., 1985; and Pike and Linquist, 1994). Other than feeding and ecological studies, only a limited amount of published information is available on age and growth and reproduction (Caldwell, 1955). However, an ongoing reproductive study on *Diplodus holbrooki* (Marta Boris, University of North Carolina at Wilmington, pers. comm.), and this work on age and growth should provide information on its basic life history.

Herein, we report the age, growth, and mortality of spottail pinfish as determined from sampling headboat landings in North Carolina. Objectives were to evaluate whole and sectioned sagittal otoliths for aging spottail pinfish, determine lengths of fish at specific ages, estimate growth parameters, construct fish age–length keys, derive weight–length and length conversion relationships, and estimate mortality from catch curves.

MATERIALS AND METHODS

Collection and analysis: Most *Diplodus holbrooki* were sampled from recreational headboats operating from North Carolina ports between 1993 and 1995. Several small spottail pinfish (55–180 mm TL), excluded from the hook and line fishery by their size, were collected by cast nets and baited fish traps (modified crab pots). Juveniles were collected by cast net in the Newport River estuary near Pivers Island, whereas those captured in modified crab pots came from the headboat fishing grounds. Sagittal otoliths from 349 fish were studied, most from specimens caught off Beaufort, NC. Total lengths (mm) were recorded for all fish, and fork length (FL) and weight (g) were recorded when condition of fish allowed. Some fish had been cleaned, so it was impossible to obtain fish weight on those individuals.

Whole otoliths were immersed in clove oil, placed in a black-bottom watchglass, illuminated by reflected light, and examined at 12× through a dissecting microscope. Two distinct types of rings were visible: an opaque ring that appeared white, and a translucent ring that was dark. After counting the number of opaque rings, we measured distances from the otolith focus to the distal edge of each ring, from the focus to the otolith edge, and from the last ring to the otolith edge. Transverse sections of each otolith were prepared. Otoliths were aligned on paper tabs and secured with Crystalbond, mounted in a chuck to prevent lateral movement, and sectioned through the focus with a Buehler Isomet 11–180 low-speed saw. Three transverse cross-sections (0.19–0.21 mm) were mounted on glass slides with Crystalbond. Clove oil was applied to each section by pipette, and they were viewed under a dissecting scope at 25× with the aid of reflected light. Measurements as described above were recorded for each legible otolith section.

Validation: Marginal increment analysis was used to determine if opaque otolith rings formed only once each year, and could therefore, be considered annuli. Monthly mean distance plots of the last ring to the otolith margin for all age groups combined were analyzed. If the rings are formed once each year, then the plot should reveal a minimum ring-to-margin (otolith edge) increment followed by increased increment indicative of additional growth following the formation of the annulus. We also identified the months where marginal increments equaled zero. The latter analysis indicated the month(s) when the annuli were formed.

Back-calculated growth: Total lengths at age (mm) for all data were back-calculated from a fish length-otolith radius regression. The equation derived by regressing log-transformed fish length on log-transformed magnified otolith radius (OR) is $L = a(OR)^b$, where L = total length in mm. To calculate mean size at each age, the means of the distances from the focus to each ring for that age were substituted for OR in the above equation.

Growth parameters: Construction of a growth curve is useful for many purposes. Growth parameters such as mean asymptotic length (L_∞), growth coefficient (K), and age at the beginning of growth (t_o), are used to construct population models. The von Bertalanffy equation: $L_t = L_\infty (1 - e^{-k} (t - t_o))$, is the most widely used growth model and is fitted to mean back-calculated length-at-age data (Ricker, 1975; Everhart et al., 1975). We derived two equations: one using all back-calculated data; the other using back-calculated data from the last annulus only (Vaughan and Burton, 1994). Growth parameters were estimated using SAS PROC NLIN with the Marquardt Option (SAS Institute, 1982), and we weighted the data by the number of fish sampled at each age. Use of the von Bertalanffy equation allowed us to make comparisons with growth parameter results obtained for other reef finfish species.

Size relationships: To describe the relationship of weight to length we used log-log regression and transformed the equation to: $W = aL^b$, where W = weight in grams, and L = total length in millimeters. Linear relationships: TL = a + b (FL) and FL = a + b (TL) were used to convert fish lengths.

Fish age–fish length keys: Observed ages at lengths (lengths of fish at time of capture for each age) were used to derive a fish age-fish length key. Fish for

Table 1. Mean observed total lengths at age from whole otoliths and sectioned otoliths for spottail pinfish collected from North Carolina.

	Whole		Sectioned	
Age	TL ± 1 SD	n	TL ± 1 SD	n
1	151 ± 7.1	33	151 ± 7.6	30
2	180 ± 12.9	18	178 ± 14.0	18
3	211 ± 20.8	21	204 ± 14.3	17
4	234 ± 18.1	48	232 ± 11.8	33
5	246 ± 16.6	59	242 ± 14.2	43
6	258 ± 22.2	80	253 ± 16.9	51
7	275 ± 19.9	50	273 ± 19.0	36
8	308 ± 13.7	12	290 ± 22.8	19
9	319 ± 20.5	11	313 ± 15.4	10
10	338 ± 22.4	5	328 ± 21.4	6
11	347	1	330 ± 10.6	2
Totals		338		265

which ages had been determined were assigned to 25-mm size intervals. Age distribution (as percent) was identified for each size interval.

Mortality estimates: Total instantaneous mortality was estimated by analyzing catch curves (Beverton and Holt, 1957) based on fully recruited age 6 fish and older. The fish age-fish length key described above was used to construct catch curves by assigning ages to landed fish that had not been aged. If the log of the age frequency in the catch is plotted on age, the slope of the descending right limb of the curve was equal to the mean instantaneous rate of total mortality (Z) assuming constant recruitment and survival (Everhart and Youngs, 1981).

RESULTS

Fish ages: Whole and sectioned sagittal otoliths were evaluated to determine ages for spottail pinfish. Whole otoliths were more useful for aging the species than sections of the otolith. Sections were more difficult and time consuming to prepare, the rings were less distinct than those counted for whole otoliths, and there was a definite problem with double ring formation. The latter was especially evident for some sections with four or more rings. The same otoliths examined whole revealed a single ring. The more detailed examination provided by viewing sections often presented a ring with strong outer and inner bands, which resembled two rings. This is the first time that the senior author has encountered the situation where whole otoliths were judged to be more reliable than sectioned otoliths for aging a reef fish species. Sample sizes for whole (n = 338) and sectioned otoliths (n = 265) were different because some sections illustrated double ring formation, and some sections broke while they were being cut. Thus, fewer sectioned otoliths could be used in the analyses.

Of the 349 whole otoliths examined, 338 (97%) could be aged, and 322 (92%) were legible enough to record growth measurements. Fish were aged 0–11 years. Individuals at capture averaged 151 mm TL at age 1, 246 at age 5, and 338 at age 10 (Table 1). Although sectioned otoliths yielded similar mean observed lengths at ages as whole otoliths (Table 1), sections were more difficult to interpret and measure. Thus, further evaluations used data from whole otoliths. Most fish

Table 2. Back-calculated lengths (using log formula) for spottail pinfish collected from North Carolina headboat fishery.

			Ring										
Age	n	Observed TL ± 1 SD	1	2	3	4	5	6	7	8	9	10	11
1	322	151 ± 7	122										
2	289	180 ± 13	119	168									
3	271	211 ± 21	121	170	199								
4	253	234 ± 18	121	169	200	223							
5	205	246 ± 17	119	166	195	216	233						
6	149	258 ± 22	118	167	197	218	235	249					
7	71	275 ± 20	121	169	198	221	239	253	266				
8	26	308 ± 14	122	173	205	230	249	264	278	288			
9	14	319 ± 20	122	177	215	239	254	269	280	290	299		
10	5	338 ± 22	117	169	200	225	244	259	272	283	290	297	
11	1	347	104	151	194	219	244	264	283	290	296	303	310
Weighted Means ± 1 SE			120 ±0.5	168 ±0.6	198 ±0.7	221 ±0.9	237 ±1.0	253 ±1.3	270 ±2.0	288 ±2.8	296 ±3.8	298 ±7.6	310
Annual Increment			120	48	30	23	16	16	13	18	8	2	13

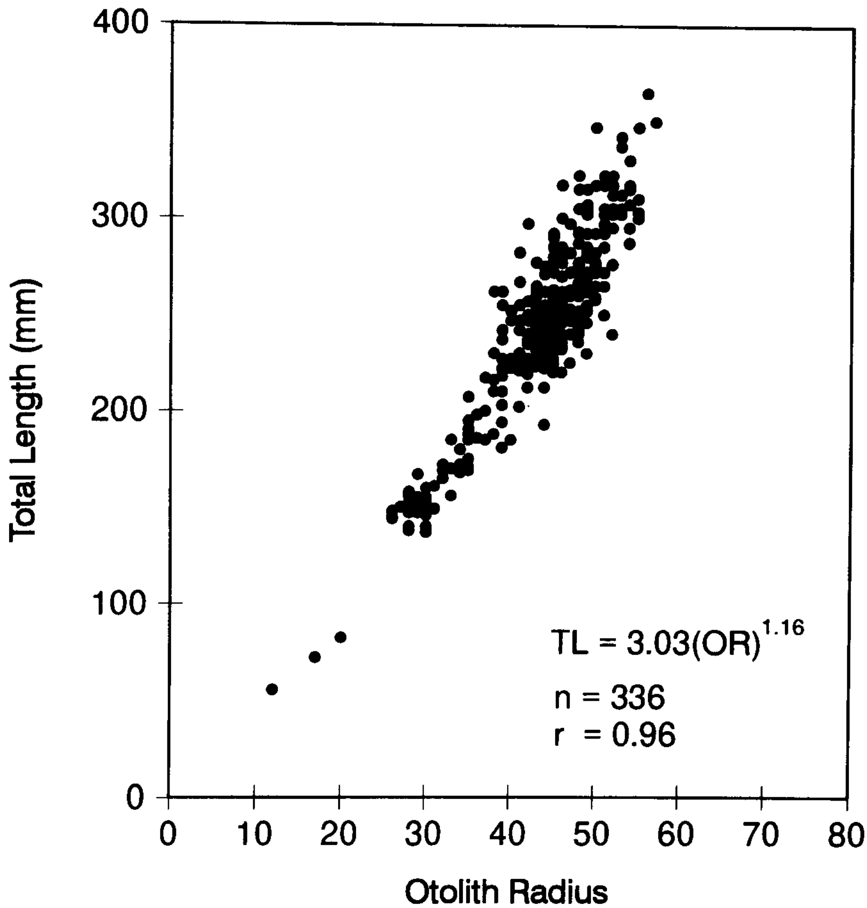

FIG. 1. Total length - otolith radius relationship for spottail pinfish collected from North Carolina.

specimens were collected from dockside headboat landings from February through October, and ranged in size from 200–365 mm TL. The exceptions were three juveniles (55–82 mm TL) collected with cast nets, and 50 individuals (100–185 mm TL) obtained from modified crab pots.

Validation: The usefulness of any calcareous structure to estimate fish age should first be determined. Critical to this decision, there must be a positive relationship between the size of the fish and size of the structure (i.e., the larger the fish, the larger the structure). Also the rings must be consistently located on the structure and most be formed periodically, that is, in our study, yearly. Several observations support the use of whole otoliths for aging spottail pinfish and validate rings as annual marks. First, the mean lengths of fish progressively increased as the number of rings (ages) increased (Tables 1–2), second, there was a strong correlation between otolith radii and fish lengths ($r = 0.94$; Fig. 1), and third, marginal increment analyses reveal ring formation during March-May (Fig. 2). The latter was confirmed by documenting months when zero marginal increment occurred (Fig. 3). Approximately 95% of the zero increment measurements were

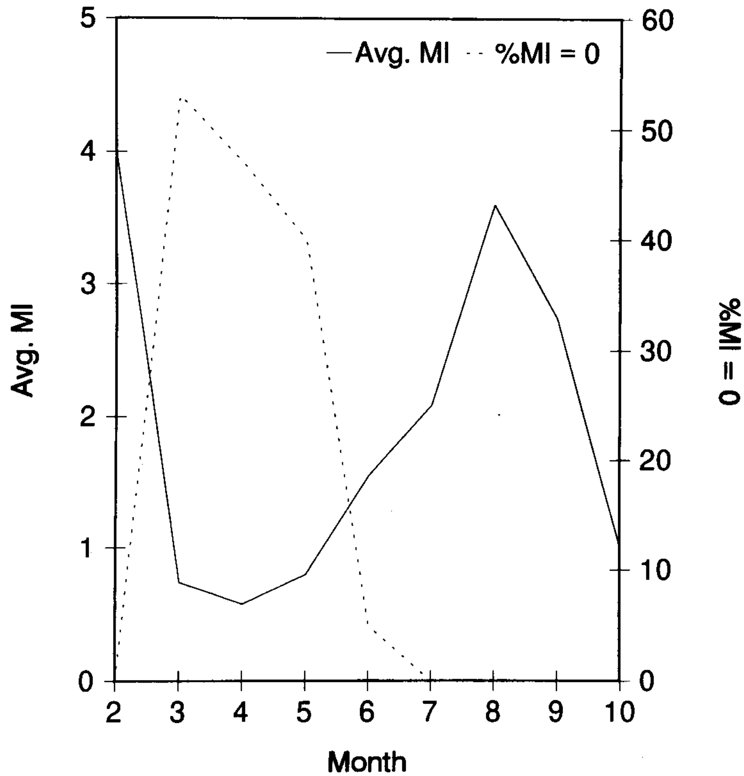

FIG. 2. Marginal increment (MI) analysis of spottail pinfish, age 1–11, collected off North Carolina. MI = 0 means margin was opaque.

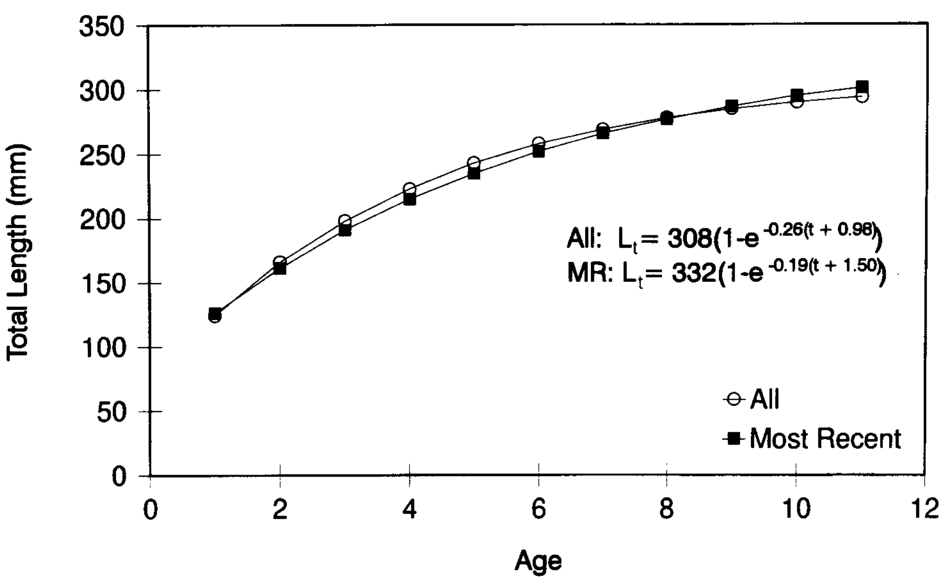

FIG. 3. Theoretical total length (mm) at age based on all back-calculated data and last annulus back-calculated data.

Table 3. Theoretical growth parameters using all back-calculated data (All B-C) and the last annulus back-calculated data (MR B-C) with 95% confidence intervals (C.I.) (log equation).

Type	L_∞	95% C.I.	K	95% C.I.	t_o	95% C.I.
All B-C	307.63	302–314	0.26	0.24–0.27	−0.98	−1.07–−0.89
MR B-C	331.98	314–350	0.19	0.16–0.22	−1.50	−1.81–−1.19

recorded in March–May. This annulus formation period was identical to the one recently observed for the reef fish species, red hind, *Ephinephelus guttatus,* and rock hind, *E. adscensionis* (Potts and Manooch, 1995).

Back-calculated growth: Lengths at ages, using all data, were back-calculated using the otolith radius–fish length regression: TL = 3.03 $(OR)^{1.16}$ (n = 336; r = 0.94). By substituting the means of the distances from the otolith focus to each annulus for OR in the above equation, we calculated the mean length of the fish at the time of each annulus formation, and the mean annual growth increment at each age (Table 2). Growth was rapid during the first year (120 mm), gradually declined during the second through the fifth years, remained stable during the fifth through the eighth years, and was slow, apparently erratic, for the ninth through 11th years (Table 2). Sample sizes were small for ages 10 and 11, only five and one, respectively. Mean back-calculated total lengths ranged from 120 mm for age 1 to 309 mm TL for age 11.

Growth parameters: Growth parameters (L_∞, K, and t_o) were derived using two different methods. In one, all back-calculated mean size at age data (ages 1–11), weighted by the inverse of the number of fish of each age, were used to derive the growth model: $L_t = 308\ (1 - e^{-0.26(t+0.98)})$. In the other, only the mean back-calculated data from the last annulus was used to generate the equation: $L_t = 332\ (1 - e^{-0.19\ (t+1.50)})$. The parameters for both equations are shown in Table 3 with 95% confidence limits, and theoretical lengths at ages are presented graphically in Figure 3 and are also tabulated (Table 4).

Theoretical growth parameters have been derived for three species of reef sparid fishes that co-occur with *D. holbrooki* off North Carolina: red porgy, *Pagrus*

Table 4. Mean observed total lengths, back-calculated lengths and theoretical lengths from all the back-calculated data and the most recent data (log equation).

		Back-calculated		Theoretical	
Age	Obs.	All	Most Recent	All	Most Recent
1	150	120	122	124	126
2	180	168	168	166	161
3	211	198	199	198	191
4	234	221	223	223	215
5	246	237	233	243	235
6	258	253	249	258	252
7	275	270	266	269	266
8	308	288	288	278	277
9	319	296	299	285	287
10	338	298	297	290	295
11	347	310	310	294	301

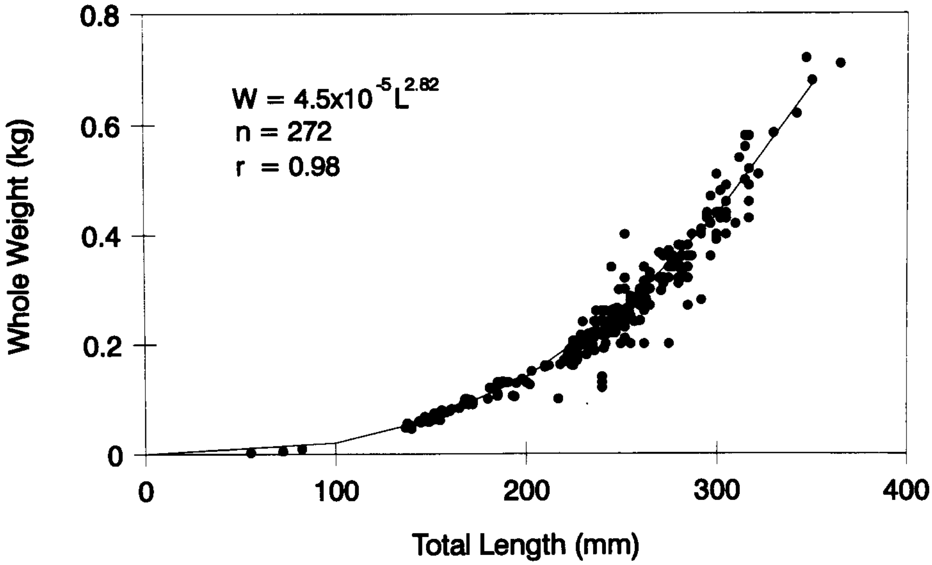

FIG. 4. Weight - length relationship for spottail pinfish collected off North Carolina.

pagrus, knobbed porgy, *Calamus nodosus,* and whitebone porgy, *C. leucosteus.* Another sparid, the sheepshead, *Archosargus probatocephlus,* co-occurs inshore, but is not found in offshore reefs. The three reef fish species are capable of obtaining larger sizes than the spottail pinfish, and grow slower and live longer (Manooch and Huntsman, 1977; Waltz et al., 1982; Horvath et al., 1990). Mortality estimates for spottail pinfish were essentially identical when comparing

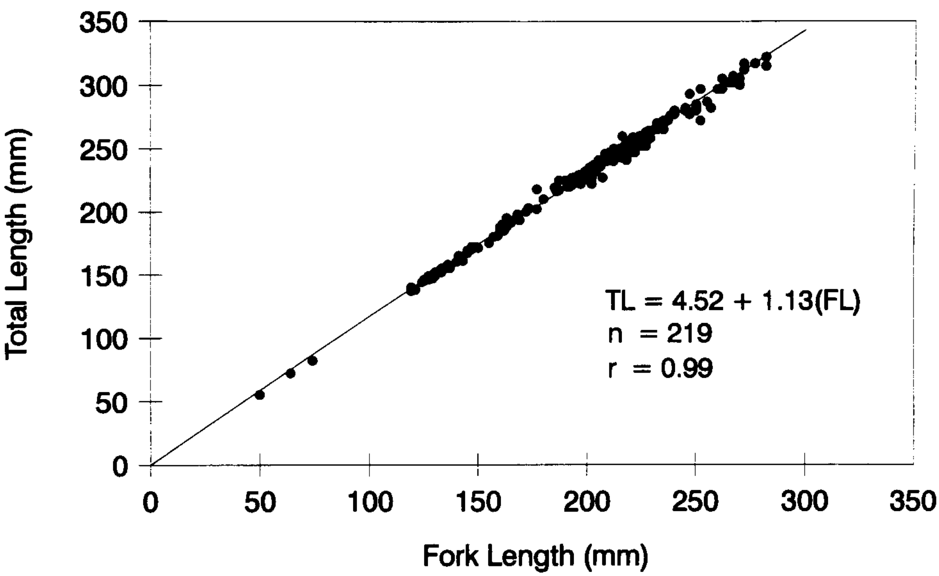

FIG. 5. Total length - fork length relationship for spottail pinfish collected off North Carolina.

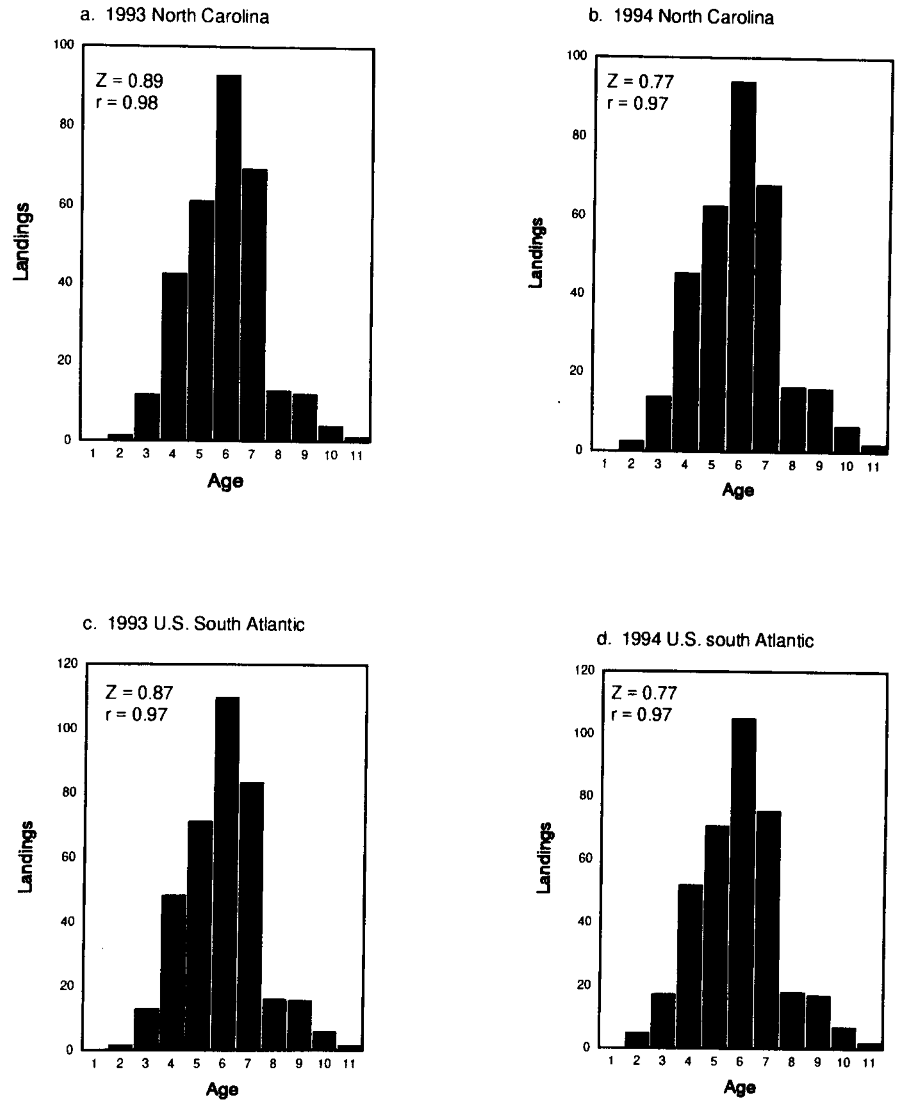

FIG. 6. Catch-at-age and estimates of Z from headboat data for spottail pinfish, 1993 and 1994. North Carolina (a,b), South Atlantic (c,d).

years for each area. Estimated rates were higher in 1993 (Z = 0.87; 0.89) than 1994 (Z = 0.77).

Weight–length relationship: To convert fish lengths into fish weights and vice versa, we derived the equation: $W = 4.5 \times 10^{-5}\ TL^{2.82}$ ($n = 272$; $r = 0.98$), where W = grams (Fig. 4). Thus, a 150 mm TL fish is predicted to weigh 62 g, whereas fish measuring 250 and 350 mm are predicted to weigh 260 g and 672 g, respectively.

Fish length conversions: The following linear relationships were derived to con-

Table 5. Age–total length key for spottail pinfish collected from North Carolina. Figures in ( ) are the percent of samples in that age category at that size interval.

Total Length Class (25 mm)	Age 1	2	3	4	5	6	7	8	9	10	11
125	15 (100.0)										
150	18 (69.23)	8 (30.77)									
175		9 (52.94)	7 (41.48)	1 (5.88)							
200		1 (4.00)	8 (32.00)	13 (52.00)	1 (4.00)	2 (8.00)					
225			5 (5.10)	23 (23.47)	35 (35.71)	31 (31.63)	4 (4.08)				
250			1 (1.27)	10 (12.66)	18 (22.78)	28 (35.44)	22 (27.85)				
275				1 (2.56)	5 (12.82)	14 (35.90)	16 (41.03)	1 (2.56)	2 (5.13)		
300						5 (16.67)	8 (26.67)	10 (33.33)	5 (16.67)	2 (6.67)	
325								1 (14.29)	3 (42.86)	2 (28.57)	1 (14.29)
350									1 (50.00)	1 (50.00)	

vert fish lengths: TL = 4.52 + 1.13 (FL) (n = 219; r = 0.99), and FL = 02.75 + 0.88 (TL) (n = 219; r = 0.99) (Fig. 5).

Age–length key and mortality: Estimates of total instantaneous mortality (Z) were obtained by using catch curves for fish landed in North Carolina (Fig. 6a,b) and from along the southeastern United States, North Carolina through the east coast of Florida (Fig. 6c, d) for 1993 and 1994. The catch curves were produced using a fish age-fish length key (Table 5). Mortality estimates were obtained to compare years for each area: Z = 0.89 for North Carolina in 1993, 0.77 for 1994; Z = 0.87 for the U.S. South Atlantic for 1993, and 0.77 for 1994.

Management: At present, the spottail pinfish does not appear to be an overexploited reef fish species. However, its popularity, particularly with recreational headboat anglers, is growing rapidly, and the species may become more accepted by commercial markets as well. The reason for the increased landings is unknown. However, one theory is that as red porgy have been overfished, and locally depleted, spottail pinfish have successfully filled the same, or very similar, niche, and the spottail pinfish population has expanded (senior author, pers. obs.). The increase in harvest will necessitate that researchers and managers monitor stock characteristics of the species closely, including information pertaining to age and growth.

Should management options become necessary in the future, the species should respond well to a variety of management strategies. Our observations indicate that spottail pinfish are hardy, and when caught from their typical shallow-water habitats, could be returned unharmed. Thus, management options such as a daily bag limit, or a minimum allowable size of fish harvested may be effective.

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